Simultaneous Off-Resonance Correction and Fat/Water Separation for Non-Cartesian Trajectories using a Multi-Frequency Least-Squares Approach

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Introduction One of the major disadvantages of non-Cartesian trajectories is that they suffer from chemical shift and off-resonance blurring. However, if multiple echoes are acquired, it is possible to both separate the fat signal and correct for blurring due to field variations by using multi-frequency Dixon reconstructions [1]. However, current methods require specific echo times where water and fat are in-phase and out-of-phase and may not produce optimal SNR. Here, we present a multi-frequency least-squares method which supports the selection of arbitrary echo times, allowing for optimal SNR performance [2] or shorter repetition times.

Methods Figure 1 shows the algorithm. In the example, a spiral trajectory is used to image a 36 cm FOV with in-plane resolution of 1.25 mm. Each 17 ms spiral readout is acquired at 3 different arbitrary echo times (TE1=10.2 ms, TE2=11.8 ms, and TE3=13.2 ms). An SPGR pulse sequence with a flip angle of 15 degrees was used on a GE Excite 1.5 T system. An 8-channel cardiac coil was used for signal reception.

The method relies on the matrix equation which assumes that the center frequency used for reconstruction is exactly correct at each voxel:

$$\begin{bmatrix} image1_{cf} \\ image2_{cf} \\ image3_{cf} \end{bmatrix} = \begin{bmatrix} 1 & \exp(-i \cdot 2\pi \cdot TE1/4.6ms) \\ 1 & \exp(-i \cdot 2\pi \cdot TE2/4.6ms) \\ 1 & \exp - i \cdot 2\pi \cdot TE3/4.6ms) \end{bmatrix} \cdot \begin{bmatrix} W \\ F \end{bmatrix} = A \cdot \begin{bmatrix} W \\ F \end{bmatrix}$$

where $imageX_{cf}$ corresponds to echo time X and center frequency *cf*, and *W* and *F* correspond to the water signal and fat signal in each voxel respectively. Solving the equation using the complex least-squares pseudo-inverse of A (*pinv*(*A*)) gives:

$$\begin{bmatrix} \tilde{W}_{cf} \\ \tilde{F}_{cf} \end{bmatrix} = pinv(A) \cdot \begin{bmatrix} image1_{cf} \\ image2_{cf} \\ image3_{cf} \end{bmatrix}.$$

These estimates are generated for a range of center frequencies (say -100 to 100 Hz). These estimates of the water and fat signals are then substituted into the orginal matrix equation to create re-synthesized versions of the images for each echo time, from which a difference with the actual measured result (or 'residual') can be determined for each voxel and each center frequency. Using the voxel from the water estimate with center frequency corresponding to the minimum residual (the one in which the assumption in the orginal matrix equation is most correct) provides a completely fat-suppressed, deblurred image. A fat-only image can be created using the same technique with a positive sign in the exponents in matrix A and shifted center frequencies.

Results/Discussion The results shown in Figure 1 demonstrate that this technique successfully suppresses fat and deblurs the image, even in the presence of significant susceptibility. However, due to noise, the minimum residual will not necessarily always correspond to the most appropriate center frequency, and a "salt-and-pepper" type artifact may appear. Further work needs to be done on eliminating these rare errors, (perhaps by using median or smoothing filters on the residual images) before this technique will be completely robust. Nonetheless, we have demonstrated the potential for excellent fat-water suppression and simultaneous off-resonance deblurring for non-Cartesian trajectories with arbitrary echo times using a multi-frequency least-squares method.

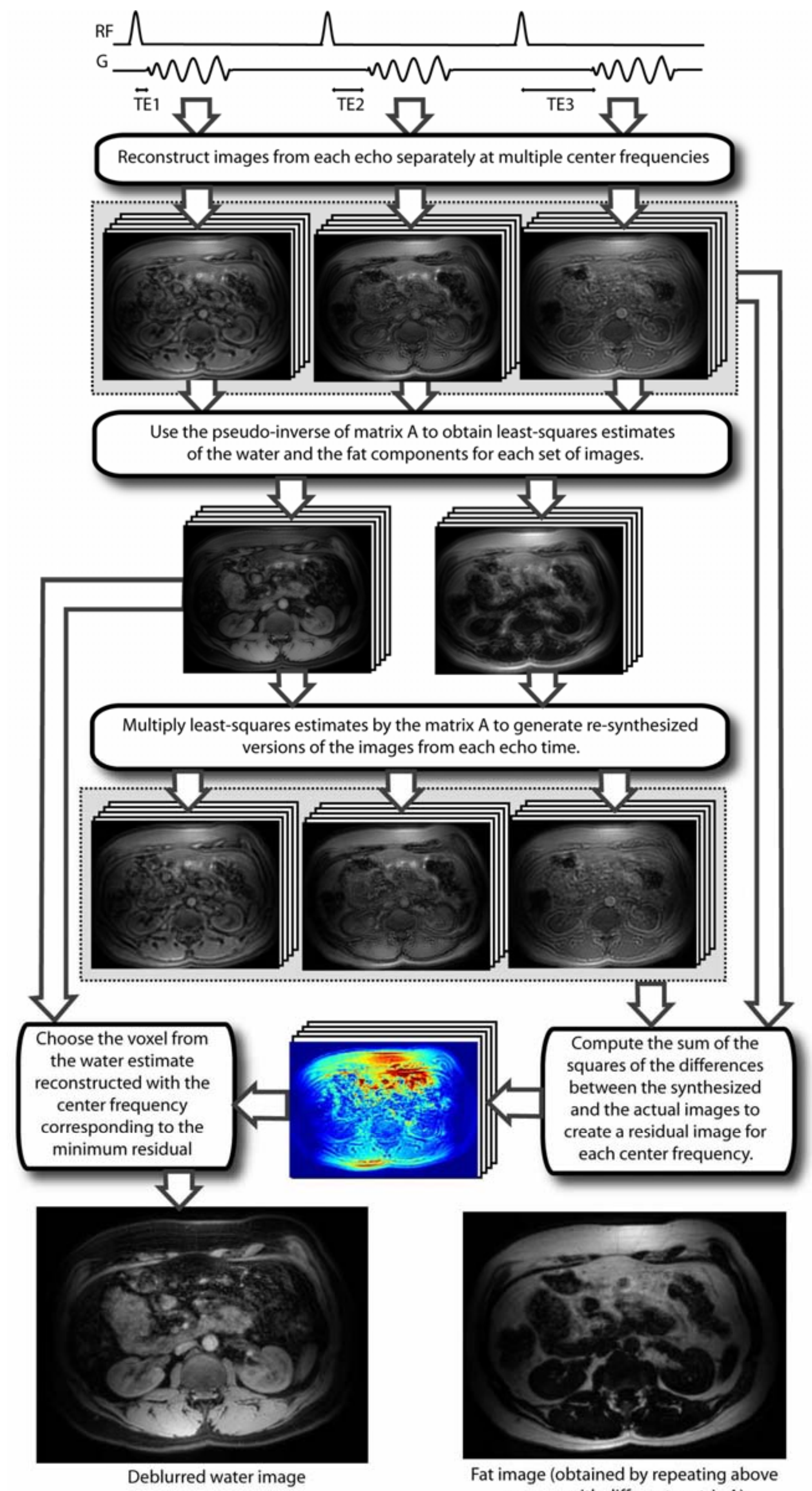

Figure 1: *Schematic showing the multi-frequency least-squares approach.*

References [1] Moriguchi et al, MRM 2003; 50(5):915-24. [2] Reeder S et al, MRM 2004; 51(1):35-45.